Task Validation of Display Temporal-Resolution Measurements

Marc D. Winterbottom	George A. Geri	Lisa Park
Air Force Research Laboratory	**Link Simulation and Training**	**Link Simulation and Training**
Mesa, AZ 85212	**Mesa, AZ 85212**	**Mesa, AZ 85212**
Marc.Winterbottom@mesa.afmc.af.mil	George.Geri@mesa.afmc.af.mil	Lisa.Park@mesa.afmc.af.mil

ABSTRACT

We have recently described both engineering and perceptual techniques for assessing the temporal resolution (i.e. moving image blur) of display systems used in Air Force flight-simulator applications. These techniques have subsequently been used on a variety of display devices. The engineering techniques were developed primarily to provide an objective measurement standard analogous to those accepted by the displays industry. The perceptual techniques were designed to extend the measurement standard by assessing the response of human observers to relatively simple test stimuli. In the present study, we have attempted to validate our previous techniques by correlating them directly with performance on a simplified air-to-air task that may be performed in high-fidelity Air Force flight simulators. This flight performance data was obtained by asking observers to judge whether or not an F-16 target banked in a direction indicating that it was turning toward the observer. This task was performed for a target distance of 1600 m, three target speeds, and 4 levels of display temporal resolution (i.e. 4 levels of moving image blur). The results indicated that decreasing temporal resolution led to poorer performance on the roll detection task. However, results with temporal resolution closer to that of a CRT resulted in significantly improved performance. Minimum display temporal resolution required for flight simulation visual displays is discussed.

ABOUT THE AUTHORS

Marc D. Winterbottom is a Research Psychologist in the Visual Systems Research Laboratory at Air Force Research Laboratory in Mesa, Arizona. His research focuses on visual perception, particularly as it relates to display technologies for simulation and training applications. He received a M.S. degree in Human Factors Psychology from Wright State University (2000) and a B.A. degree in Psychology from Purdue University (1996).

George A. Geri is a Senior Scientist and Visual Research Team Leader with Link Simulation and Training in Mesa, Arizona. Dr. Geri received a B.S. degree in Psychology (1972) and a Ph.D. in Physics (1979) from Rensselaer Polytechnic Institute, Troy, N.Y., and completed a National Research Council Postdoctoral Associateship in 1981. Dr. Geri's major research interests are visual perception and image analysis, especially as they relate to flight simulation, and the perceptual and engineering evaluation of high-resolution visual displays. Dr. Geri has published more than fifty technical papers in various areas of visual science including space and form perception, image processing, eye-movement analysis, binocular vision and stereopsis, image compression, color vision, clinical vision, visual electrophysiology, and visual system anatomy.

Lisa Park is a Simulation and Training Specialist with Link Simulation and Training in Mesa, Arizona. She received an M.S. and a B.A. degree in Applied Psychology from Arizona State University (2006, 2003 respectively). Since 2003, she has worked with the Performance and Learning Models (PALM) laboratory and the Visual Systems Research Laboratory at Air Force Research Laboratory.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **NOV 2007**	2. REPORT TYPE **Final**	3. DATES COVERED **01-01-2006 to 30-11-2007**

4. TITLE AND SUBTITLE **Task Validation Display Temporal-Resolution Measurements**	5a. CONTRACT NUMBER **FA8650-05-D-6502 TO 10**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER **62202F**
6. AUTHOR(S) **Marc Winterbottom; George Geri; Lisa Park**	5d. PROJECT NUMBER **1123**
	5e. TASK NUMBER **AE**
	5f. WORK UNIT NUMBER **1123AE07**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory/RHA,Warfighter Readiness Research Division,6030 South Kent Street,Mesa,AZ,85212-6061**	8. PERFORMING ORGANIZATION REPORT NUMBER **AFRL; AFRL/RHA**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory/RHA, Warfighter Readiness Research Division, 6030 South Kent Street, Mesa, AZ, 85212-6061**	10. SPONSOR/MONITOR’S ACRONYM(S) **AFRL; AFRL/RHA**
	11. SPONSOR/MONITOR’S REPORT NUMBER(S) **AFRL-RH-AZ-PR-2007-0007**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
In Proceedings of the 2007 Interservice/Industry Training, Simulation and Education Conference (IITSEC) held 26-29 Nov 07 in Orlando FL (Paper No. 7274)

14. ABSTRACT

We have recently described a perceptual technique for assessing the temporal resolution of display systems used in Air Force flight-simulators. That technique was based on the assessment of the perceived blur of a simple stimulus consisting of a pair of moving vertical lines. In the present study, we have attempted to validate our previous technique by correlating it directly with performance on simplified tasks that may be performed during training in a high-fidelity Air Force flight simulator. Data were obtained by asking observers to; (a) detect whether or not a moving F-16 target-aircraft banked as it moved laterally across the observers' field-of-view, and (b) judge whether changes in aircraft pitch resulted in blurring of the associated moving terrain. The level of moving-image blur was determined by the length of time that the image was presented during each video frame (i.e., the projector hold-time) on a digital (DLP) projector. The results were compared to those obtained using a standard CRT projector, whose effective hold-time was about one-quarter of that of the lowest DLP hold-time tested. For both the roll detection task and the aircraft pitch task, results with the DLP projector did not differ significantly from that obtained with the CRT when the DLP hold-time was reduced to 5.8 msec. These results are in qualitative agreement with those obtained using the simpler moving-line test, and suggest that the latter is a valid measure of display temporal resolution in the context of flight-simulator applications.

15. SUBJECT TERMS

Perceptual technique; Temporal resolution; Display systems; Flight simulators; Training; Moving image blur; Images; Digital projectors; Display temporal resolution;

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Public Release**	**6**	

Task Validation of Display Temporal-Resolution Measurements

Marc D. Winterbottom
Air Force Research Laboratory
Mesa, AZ 85212
Marc.Winterbottom@mesa.afmc.af.mil

George A. Geri
Link Simulation and Training
Mesa, AZ 85212
George.Geri@mesa.afmc.af.mil

Lisa Park
Link Simulation and Training
Mesa, AZ 85212
Lisa.Park@mesa.afmc.af.mil

INTRODUCTION

Digital displays, such as Liquid-crystal displays (LCDs), Liquid Crystal on Silicon (LCoS), Digital Light Projectors (DLP), FerroElectric Liquid Crystal on Silicon (FLCoS), etc., have relatively high spatial resolution, but their temporal resolution is limited compared to CRTs. This limited temporal resolution often results in the blurring of moving images (Klompenhouwer & Velthoven, 2004; Kurita, 2001; Nakamura & Sekiya,. 2001). It was originally believed that moving-image blur was due to the long onset and offset times typical of LCDs, which were often longer than the frame duration. However, the onset and offset times of LCDs have been reduced significantly over the past ten years, and so their limited temporal response seems now to be a consequence of the sample-and-hold property related to both the design of the LCD driver circuitry and the LCD itself (Yamamoto, Aono, & Tsumura, 2000). Further, DLP and FLCoS displays have very fast response times (in terms of onset and offset), but still exhibit significant moving image blur. The severity of the moving image blur on displays of these types is such that they are unsuitable for flight simulation and training applications.

In previous work (Winterbottom, *et al*, 2004, 2006, 2007) we described a relatively simple procedure for measuring display spatial and temporal resolution and observed moving image blur. Although other procedures, such as the Motion Picture Response Time (MPRT), have been proposed (see e.g. Igarashi, et al, 2003; Oka, & Enami, 2004; Igarashi, et al, 2004), they are generally more complex, require more expensive equipment, and do not directly measure perceived blur. We also reported that LCD and LCoS projectors equipped with mechanical shutters that reduced pixel hold-time resulted in a significant reduction in perceived blur. Further, experienced pilots who viewed the resulting imagery rated moving image quality as significantly higher when the shutter was used. It was shown that reduction of hold-time to 4 ms was not statistically different from a CRT display. However, it remained to be determined what effect moving image blur had on the performance of tasks relevant to flight simulation and what level of blur reduction may be acceptable for the performance of these tasks.

In the present study, we have attempted to validate our previous techniques by correlating them directly with performance on a simplified air-to-air task that may be performed in high-fidelity Air Force flight simulators.

DISPLAY CHARACTERIZATION

A Christie Matrix S+2K DLP projector and Barco 909 CRT projector were used for testing and experimentation. The Christie DLP projector was equipped with a function called Accuframe, which allowed temporal-resolution (i.e. hold-time) to be adjusted.

Methods

Spatial Resolution

Display spatial resolution was assessed using techniques adapted from accepted measurement standards (Geri, Winterbottom & Pierce, 2004; VESA, 2001). This involved measurement of contrast for grille lines 3, 2, and 1 pixels wide. Resolution was determined by dividing the number of addressed lines by the grille line width required to reach 25% contrast. Luminance and gamma measurements were also obtained.

Temporal Resolution: Display Temporal Response

Temporal resolution was measured using a photodiode and Fluke Scopemeter. Each display's response to a 30 Hz test pattern was recorded.

Temporal Resolution: Perceived Blur

Observers were instructed to track a test pattern consisting of two white vertical lines (DAC = 255) moving at speeds ranging from 4 to 45 deg/sec (100 to 1200 pixels/sec). The background was black (DAC = 0), and the lines were 100 pixels in length,and 1 pixel wide. Observers adjusted the separation between the lines such that a gap between them was just visible and such that the lines were equal in width. If the lines appeared blurred (i.e.

appeared to be wider than 1 pixel), gap width necessarily increased, thus the adjusted gap width was taken as a measure of perceived blur.

Results

Michelson contrast as a function of grille line width for each projector and two Accuframe settings is shown in Figure 1. The number of addressed pixels was 1400 × 1050 and 1280 × 1024 for the DLP and CRT, respectively. As shown in Figure 1, contrast for either display does not drop below the VESA criterion (25%) for any grille width, thus the measured and nominal resolutions are equal. Use of the Accuframe function had little effect on spatial resolution.

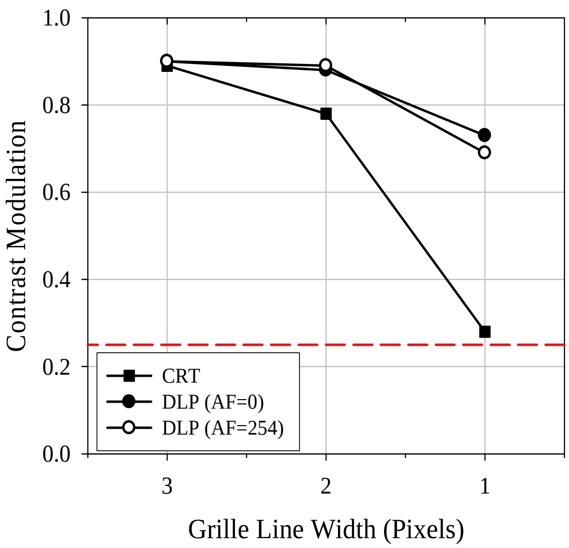

Figure 1. Michelson contrast as a function of grille line width for DLP projector at two Accuframe settings and for the CRT display.

Luminance measurements for the DLP at each Accframe setting and for the CRT display were obtained. As might be expected, increasing the Accuframe setting (reducing hold-time) also reduced luminance. Maximum luminance for the DLP with Accuframe = 0 was approximately 100 fL. Maximum DLP luminance with Accuframe = 254 was approximately 34 fL. CRT maximum luminance was approximately 15 fL.

Shown in Figure 2 are measurements of temporal response for the DLP display at two Accuframe settings (AF = 0, AF =254). Measured hold-time (50% amplitude) for the CRT and the DLP using the 0, 128, and 254 Accuframe settings was 1.4, 16.6, 7.4, and 5.8 milliseconds, respectively. Use of the Accuframe function at maximum (AF = 254) reduced hold-time by 65%.

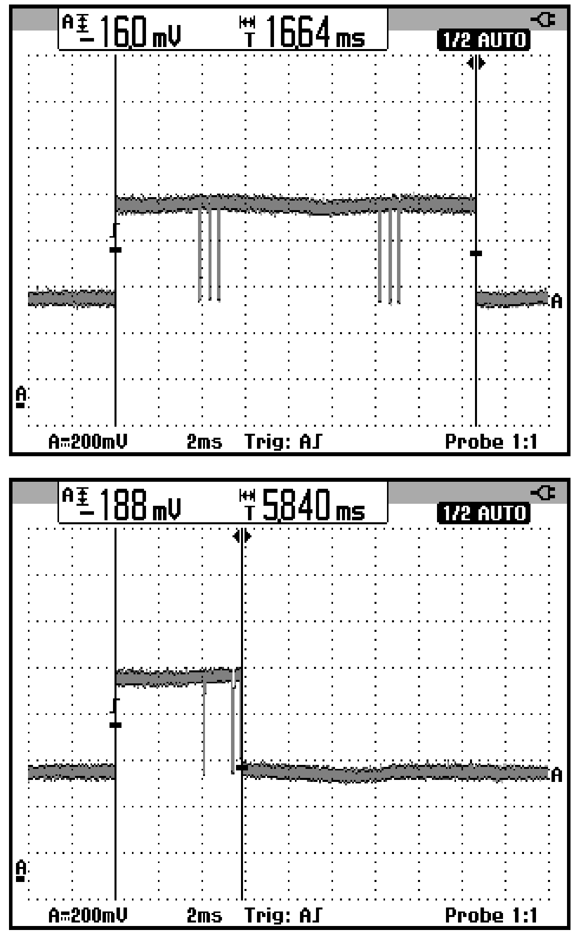

Figure 2. Response of the DLP for two Accuframe settings to a 30 Hz test pattern.

Shown in Figure 3 is perceived blur as line speed was varied for each display and Accuframe setting. As shown, decreasing hold-time significantly reduces perceived blur. Analysis of Variance indicated that the effects of Speed [$F(4,40)=451$, $p < 0.001$], Hold-time [$F(3,40)=395$, $p < 0.001$] and Speed × Hold-time [$F(12,40)=73$, $p < 0.001$] were significant. Post-hoc tests indicated that the 16.6, and 8.7 msec Hold-times (AF=0, and AF = 128) resulted in perceived blur that was significantly greater than the CRT (1.4 msec Hold-time). However, perceived blur for the 7.4 msec Hold-time (AF = 254) was not statistically different (averaged across speed) from that of the CRT.

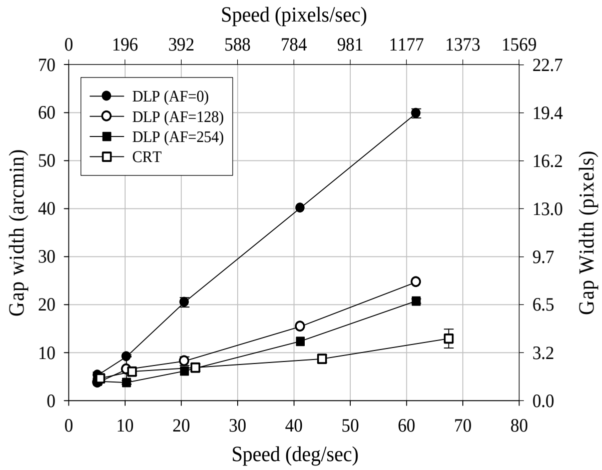

Figure 3. Perceived blur as a function of line speed and display Hold-time.

AIRCRAFT ROLL DETECTION

Methods

Observers

Four observers with normal or corrected to normal vision participated.

Apparatus and stimuli

The Barco CRT projector and Christie DLP were used to project images 52” × 43” (72° × 62°) and 52” × 29” (72° × 44°), respectively. Brightness and contrast were adjusted such that the CRT and the DLP at each Accuframe setting were of approximately equal luminance. The stimulus was an F-16 model which moved across the screen at speeds of 8.0, 17.5 and 35.0 degrees/sec (435, 957, 1961 knots). The F-16 always moved from left to right.

Procedure

The moving F-16 model was displayed for approximately 2 seconds. The F-16 rolled 4, 7, 10, 13, 16, or 19 degrees. The observers’ task was to track the motion of the aircraft and indicate, using a 2-button response box, whether or not the F-16 rolled. Roll detection accuracy was recorded for 3 levels of speed, 6 levels of roll, and 4 levels of hold-time. F-16 simulated distance was always 1600 m (a target size of approximately 34 arcmin horizontal visual angle). Observers viewed the display from a distance of 36”. Image size and viewing distance were selected to match as closely as possible the conditions in the Mobile Modular Display for Advanced Research and Training (M2DART, see e.g. Wight, Best, and Peppler, 1998).

Results

Shown in Figure 4 is roll detection accuracy for each roll angle, speed, and hold-time. As shown, performance is worst for small roll angles. Performance increased as roll angle increased. Performance was also worst for the highest speed condition. Figure 5 shows estimated threshold roll angles for each target speed and display Hold-time.

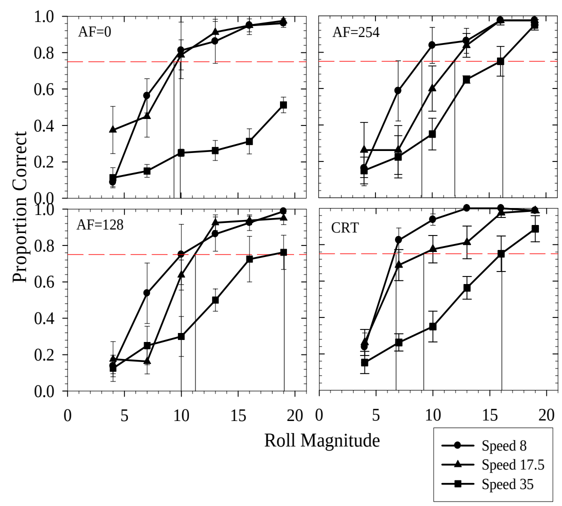

Figure 4. Proportion correct roll detection for each target roll magnitude, display Hold-time, and target speed. Vertical lines indicate threshold estimates for roll detection.

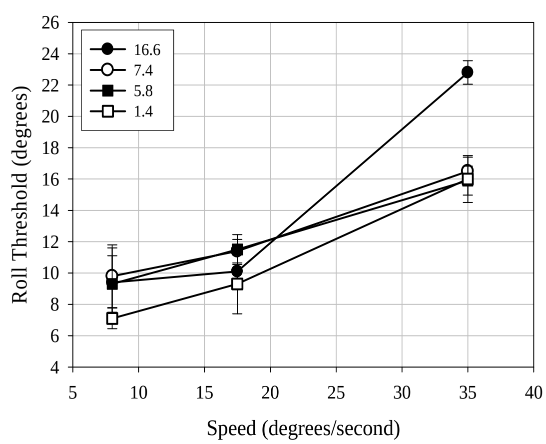

Figure 5. Roll detection thresholds for each target speed and display Hold-time.

A repeated measures ANOVA (Huynh-Feldt corrected) indicated that the effect of Hold-time was significant [$F(3, 9) = 6.7$, $p < 0.05$], effect of Speed was highly significant [$F(2, 6) = 47.4$, $p < 0.001$]. The Hold-time × Speed interaction was not significant [$F(6, 18) = 2.4$, $p = 0.13$]. Threshold generally increased with speed for all Hold-times. A set of planned contrasts indicated that roll thresholds for the 16.6 ms Hold-time were significantly different [$F(1, 3) = 70.1$, $p < 0.01$] than those for the CRT (1.4 ms Hold-time), and roll thresholds for the 7.4 ms Hold-time were marginally different [$F(1, 3) = 9.4$, $p = 0.055$], but that roll thresholds for the 5.8 ms Hold-time were not significantly different from the CRT [$F(1, 3) = 2.0$, $p = 0.25$].

Discussion

The results of the roll detection task indicated that display temporal resolution affected performance on a representative air-to-air task relevant to Air Force flight simulation. For low temporal resolution (i.e. increased Hold-time), significantly greater target roll angle was required for observer detection. Increasing temporal resolution of the DLP projector through the use of the AccuFrame function significantly improved roll detection. For the highest target speeds, performance was nearly equal for the DLP and the CRT displays. Across all speeds, there was no statistical difference in performance for the 5.8 ms DLP Hold-time and the 1.4 ms CRT Hold-time. However, as shown in Figure 5, it appears that performance with the CRT at the lowest target speed was better relative to the DLP.

Clearly, however, performance on this air-to-air task using a DLP with reduced Hold-time, and at speeds likely to be encountered in typical air-to-air scenarios, was not drastically different than that for the CRT, which is the display technology currently used in many Air Force flight simulator displays. A DLP display with Hold-time reduced to approximately 5.8 ms appears to allow acceptable performance for high speed air-to-air tasks such as the one used in this experiment. However, a more rigorous test of digital display acceptance for high speed flight simulation will be ground target detection/identification in a low altitude flight task. In this case, terrain blur will be very noticeable and may obscure ground targets.

Shown in Figure 6 is display Hold-time measured using the procedure described above versus Average Perceived Blur obtained using the Moving Line test pattern. These data were obtained for a Barco 909 CRT, Christie Matrix S+2k across three Accuframe settings, and for a shuttered LCoS projector (see Winterbottom, et al, 2007). As shown, display Hold-time accurately predicts perceived blur ($r = 0.963$, $p < 0.001$).

Figure 7 shows Perceived Blur obtained using the Moving Line test pattern vs. F-16 Roll Threshold from Experiment 1. As shown, measurement of perceived blur correlates very well with the roll angle required for accurate detection ($r = 0.82$, $p < 0.001$).

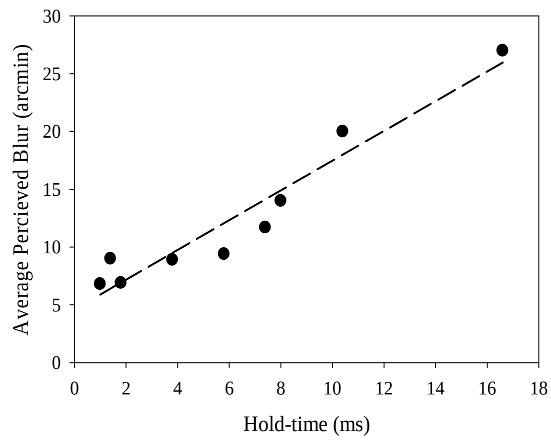

Figure 6. Average perceived blur as a function of Hold-time for a CRT, DLP with Accuframe, and shuttered LCoS projector.

The correlation among these variables suggests that a simple Hold-time measurement can be used to not only predict perceived blur, but also performance on critical flight simulation tasks. This allows for minimum display temporal resolution standards to easily be established and verified for flight simulation applications.

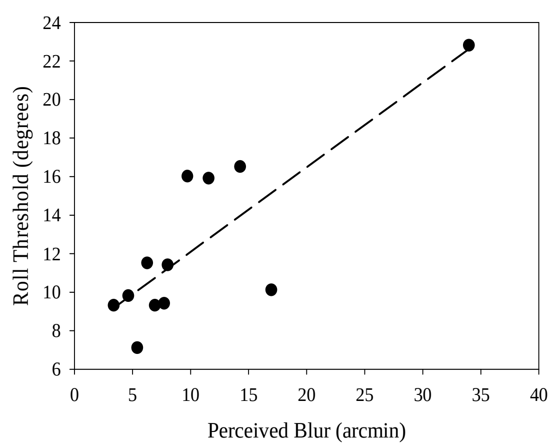

Figure 7. Perceived blur versus roll angle threshold.

The temporal resolution measurement procedure we have described here and in previous work (Winterbottom, *et al*, 2004, 2006, 2007) is simpler to administer and interpret than other methods, such as the Motion Picture Response Time (e.g. Igarashi, et al, 2003; Oka, & Enami, 2004; Igarashi, et al, 2004). This procedure is also much less expensive, requiring only a photodiode and Oscilloscope. Based on the results presented here and in our previous work with a shuttered LCoS projector, digital displays with a temporal resolution of 5.8 ms or better may be acceptable for flight simulation applications, and even displays with a temporal resolution of 6 to 8 ms may be adequate.

CONCLUSION

Moving image blur has typically only been assessed using subjective ratings, or by measuring, in various ways, amount of blur as a function of speed and display characteristics. We have described here, how display temporal resolution, and hence moving image blur, affects performance on a task relevant to flight simulation and training. The results presented here indicate that sample and hold type displays whose hold-times are reduced to 5.8 ms would likely be acceptable for fast-jet flight simulation, and that even a hold-time as high as 6 to 8 msec may be adequate. Further, we show that an easily obtainable measurement, using inexpensive equipment, is sufficient not only to predict perceived blur, but also performance on flight tasks affected by moving image blur.

ACKNOWLEDGMENTS

This work was supported by U.S. Air Force contract FA8650-05-D-6502. In addition, the following agencies provided financial and/or technical support for this research: Air Combat Command (ACC/A8AT), Secretary of the Air Force International Affairs (SAF/IA), and Defence Research and Development Canada – Toronto. We thank Bill Morgan (The Boeing Co.) for developing the simulation and data collection software and the pilots that participated in each experiment.

REFERENCES

Geri, G., Winterbottom, M., Pierce, B. (2004). Evaluating the spatial resolution of flight simulator visual displays. *Air Force Research Laboratory Technical Report Number: AFRL-HE-AZ-TR-2004-0078.*

Geri, G. & Morgan, B. (2007). The effect of FLCoS-display hold time on the perceived blur of moving imagery. *Journal of the SID*, 15 (1), pp. 87-91.

Igarashi, Y., Yamamoto, T., Tanaka, Y., Someya, J., Nakakura, Y., Yamakawa, M., Hasegawa, S., Nishida, Y., & Kurita, T. (2003). Proposal of the perceptive parameter motion picture response time (MPRT). *SID 03 Digest*, 31.2.

Igarashi, Y., Yamamoto, T., Tanaka, Y., Someya, J., Nakakura, Y., Yamakawa, M., Nishida, Y., & Kurita, T. (2004). Summary of moving picture response time (MPRT) and futures. *SID 04 Digest*, 43.3.

Klompenhouwer, M.A. & Velthoven (2004). LCD motion blur reduction with motion compensated inverse filtering. *SID 04 Digest*, 3502, 1340-1343.

Kurita, T. (2001). Moving picture quality improvement for hold-type AM-LCDs. *SID 04 Digest*, 320, 986-989.

Nakamura, H. & Sekiya, K. (2001). Overdrive method for reducing response times of liquid crystal displays. *SID 01 Digest*, 3201, 1256-1259.

Oka, K., & Enami, Y. (2004). Moving picture response time (MPRT) measurement system. *SID 04 Digest*, 43.4.

Teunissen, K., Li, X., & Heynderickx, I. (2007). Measuring motion blur in liquid crystal displays. *Information Display*, 23 (1), pp. 20-23.

VESA Flat Panel Display Measurements Standard, Version 2, Video Electronics Standards Association, Milpitas, CA, June 2001, pp.76-77.

Wight, D. R., Best, L. G., & Peppler, P. W. (1998). M2DART: A Real-Image Simulator Visual Display System. *Air Force Research Laboratory Technical Report Number: AFRL-HE-AZ-TR-1998-0097.*

Winterbottom, M.W., Geri, G.A., Morgan, W.D. & Pierce, B.J. (2004). An integrated procedure for measuring the spatial and temporal resolution of visual displays. *I/ITSEC Conference Proceedings*, Paper No. 1855.

Winterbottom, M., Geri, G., Morgan, B., Eidman, C., Gaska, J., & Pierce, B. (2006). Perceptual tests of the temporal properties of a shuttered LCD Projector. *SID 06 Digest*, pp. 494-497.

Winterbottom, M., Geri, G., Eidman, C., & Pierce, B. (2007). Perceptual Tests of the Temporal Response of a Shuttered LCoS Projector. *SID 07 Digest*, pp. 334-337.

Yamamoto, T., Aono, Y. & Tsumura, M. (2000). Guiding principles for high quality motion picture in AM-LCDs applicable to TV monitors. *SID 00 Digest*, 3101, 456-459.